Font design for high-speed impact line printers

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In impact line printers that use print-band (or similar) technology, the higher speed required of the type band for higher print throughput results in wider printed strokes with increased slur. Ordinarily, font designers compensate for the increased printed strokewidth by narrowing the width of the engraved characters on the type band. While this approach corrects the total printed character stroke, the print quality is degraded because of increased slur. This paper presents an alternative design approach in which an examination of the essential parameters of print dynamics suggests a font design that incorporates wider strokewidths.

Introduction

The print quality of the output from a high-speed impact line printer is to some extent a subjective judgment. However, there are some definable basic characteristics of printed characters that are definitely desirable in order to achieve excellent print quality [1, 2]. These characteristics are high print density or blackness, sharp edge definition, and appropriate strokewidths (neither too wide nor too thin). There are many impact line printer parameters that control print density, edge sharpness, and strokewidth. For high print density, the value of print impact force divided by character area should be high. This is controlled by the printer hammer characteristics and the font design. The ribbon or ribbon ink characteristics are also important in controlling the density of printing. The edge sharpness of the character is again controlled by the characteristics of the hammer as well as those of the paper and ribbon.

During high-speed engraved-character impact printing, short contact time between the hammer and the ribbon–paper stack is desirable as the character to be printed moves past the hammer (**Figure 1**). Short contact time means minimizing slur (**Figure 2**) and thus achieving good sharp or crisp print quality. The most significant factors that affect contact time are the impact velocity and mass of the hammer. The higher the impact velocity and the lower the mass, the lower the contact time. To a much lesser extent, character area also affects contact time: the greater the character area the lower the contact time. Thus, to achieve good print quality, higher hammer impact energies are required (most desirably achieved with low mass and high impact velocity).

While the width of printed horizontal strokes is solely determined by the strokewidth of the characters on the type band, the width of printed vertical strokes is controlled basically by font design, contact time, and band speed. As shown in Figure 2, the printed vertical strokewidth comprises a static part, the width of the stroke engraved on the band, and a dynamic part, the product of contact time and band speed. The latter product is referred to as *slur*. Thus, as mentioned above, the font design or character area plays a role in print density, edge sharpness, and strokewidth. In addition, however, the ribbon stress created by printing, which is controlled by character area and print

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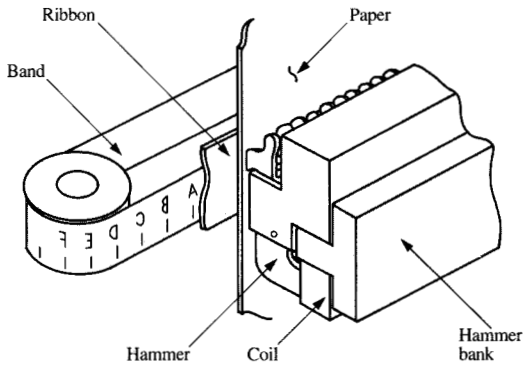


Figure 1

Band printer hammer unit.

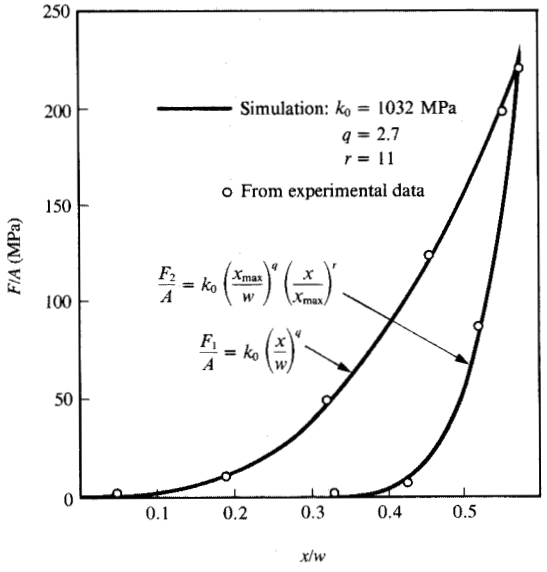


Figure 3

Ribbon–paper characteristics simulated from experimental data.

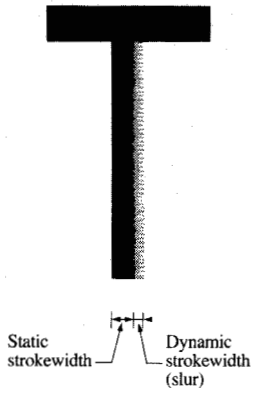


Figure 2

Illustration of slur.

energy, must be maintained below a maximum level to prevent failures in the ribbon fabric.

For impact line printers using bands, throughput is defined by Equation (1),

$$R = 60/[t_i + (Np/v_B)], \quad (1)$$

where R is throughput, or rate, in lines per minute, t_i is the vertical paper increment time (s), N is the number of characters in an array, p is the pitch of characters (m), and v_B is the horizontal velocity of the print band (m/s).

Thus, for higher-speed or "throughput" printers, performance improvement is typically obtained by increasing the band velocity. This, however, increases the slur on the vertical and slanted strokes of the characters if the contact time of the hammer unit is not proportionately reduced. As a result, not only is character slur increased, but overall printed character strokewidth is increased. The direction taken by previous font designers [3, 4] to keep the printed strokewidth constant at higher band speeds was to decrease the strokewidth on the print band. While this direction has some advantages, we believe it to have significant disadvantages. We show in this paper that a possible better alternative is to take exactly the opposite design direction and widen the strokewidths on the print band.

Theoretical considerations

The direction taken here is to increase the average character area by increasing strokewidth. The theoretical considerations of this approach are described by using a simple printing dynamics model based on rigid-mass analysis. Let us assume that the ribbon–paper behavior can be approximated by a pair of nonlinear force-deflection relationships, as used [5] in dynamics simulation **(Figure 3)**.

A schematic of the hammer impacting the ribbon–paper–print band combination is shown in **Figure 4**. The print impact force F_p is a function of the character area, the ribbon–paper characteristics, the penetration of the hammer

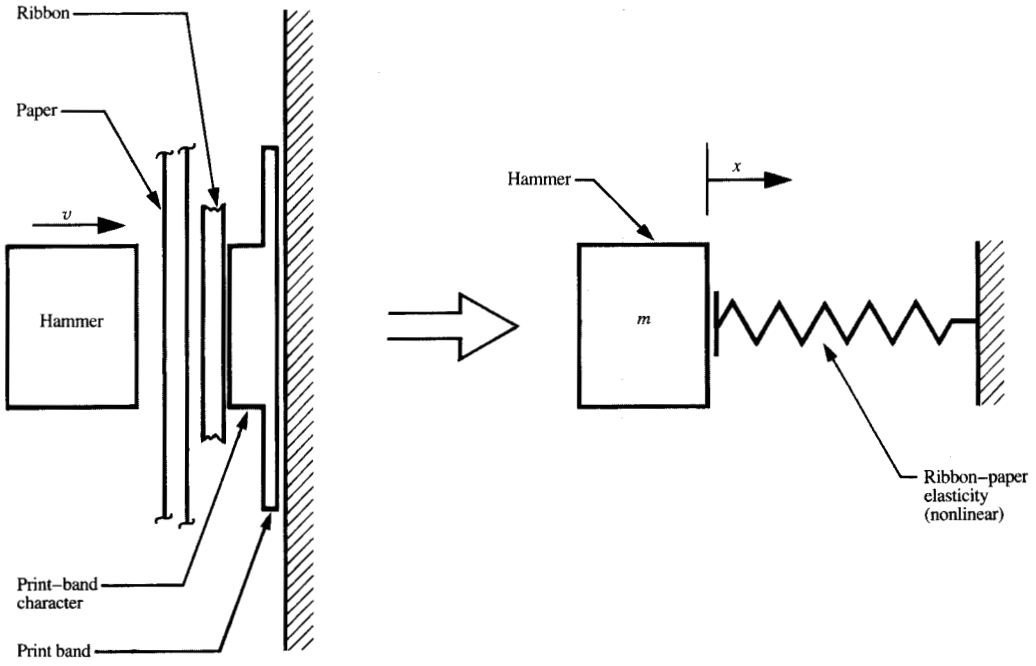


Figure 4

Schematic of hammer impacting paper, ribbon, and print band.

into the ribbon–paper, and the ribbon–paper thickness:

$$F_p = kA\left(\frac{x}{w}\right)^q \quad \text{for } \dot{x} \geq 0 \tag{2}$$

and

$$F_p = k'A\left(\frac{x}{w}\right)^r \quad \text{for } \dot{x} \leq 0 \text{ and } r > q > 1, \tag{3}$$

where F_p is the print force exerted on the ribbon–paper stack by the rigid mass m at its penetration point x; A is the area of the engraved character face; w is the ribbon–paper stack thickness; and k, k', q, and r are related to the force-deflection characteristics of the ribbon–paper stack (Figure 3). Furthermore, k and k' are related, since Equations (2) and (3) give the same value for F_p when $\dot{x} = 0$ (at $x = x_{max}$, the point of maximum penetration). The ribbon–paper behavior is thus characterized by three parameters, k, q, and r, and as shown in Figure 3, the curve F_p vs. x traces a hysteresis loop. Then, for a given hammer mass m, one can drive [5] the contact time t_C and the contact pressure $p_{max} = F_{p_{max}}/A$ to be

$$t_C = k_1 w\left(\frac{m}{2u}\right)^{\frac{1}{2}}\left[\frac{(1+q)u}{kAw}\right]^{\frac{1}{1+q}},$$

or

$$t_C \approx \left(\frac{1}{u}\right)^{\frac{q-1}{2(q+1)}}\left(\frac{1}{A}\right)^{\frac{1}{q+1}}; \tag{4}$$

$$p_{max} = k\left(\frac{u}{A}\right)^{\frac{q}{1+q}} \approx \left(\frac{u}{A}\right)^{\frac{q}{1+q}}, \tag{5}$$

where $u = mv^2/2$ represents the kinetic energy of mass m at impact velocity v. For the typical values $q = 2.7$ and $r = 11$, the value of k_1 is 3.32 and $k = 1032$ MPa.

These simple expressions show that lower energy will reduce the contact pressure but increase the contact time, degrading the print quality. However, note that an increased character area will not only lower the contact pressure but also reduce the contact time. Higher print energy (impact velocity) can now be employed, compensating for the possible loss of print quality due to increased character area.

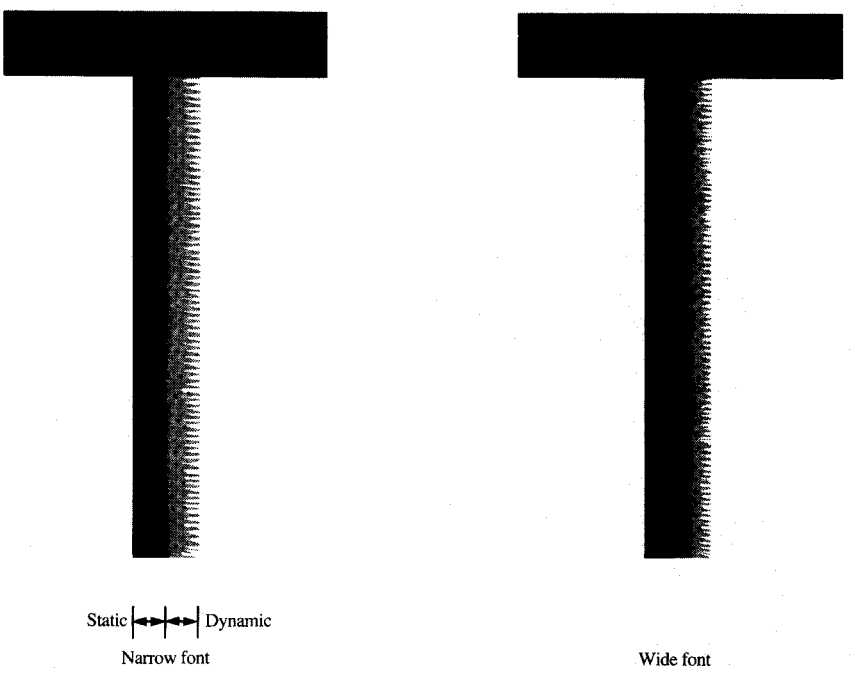


Figure 5

Example showing reduction of dynamic strokewidth (slur) by increasing the vertical strokewidth of the font.

Font design

The printed strokewidth consists of two parts, a static part and a dynamic part. This is shown in Equation (6), where S is the printed strokewidth, C is the static part, and βD the dynamic part:

$$S = C + \beta D = T(1 + \alpha) + \beta v_B t_C, \tag{6}$$

where

T = vertical strokewidth of character on print band;
α = spreading factor primarily due to paper characteristics;
v_B = band velocity;
t_C = hammer contact time;
β = percent of contact time during which band slides under pressure with respect to hammer and paper, creating slur by transferring ink to the paper.
$C = T(1 + \alpha)$ = printer character strokewidth, if the print band were stationary. This is part 1 of the total printed strokewidth and would be a dark solid printed line.
$D = v_B t_C$ = the slurred part of the printer character (vertical) strokewidth. This part would be a dark line with a great portion fading from the dark to white, giving a fuzzy or grey appearance (Figure 2).

In the past, font design has been based upon trying to decrease or maintain the printed strokewidth at high printing speeds by reducing T. However, superior print quality can be and has been obtained by doing just the opposite, i.e., increasing T. This is because increasing T increases the static part of the strokewidth (dark solid line), but even more importantly decreases the size of the fuzzy or dynamic part of the strokewidth. This is shown mathematically below, and schematically in **Figure 5**. **Figure 6** shows experimental results for the character J. The horizontal strokewidth parts of the characters show the difference in static strokewidth.

With $q = 2.7$ in Equations (4) and (5), and noting that the font area is proportional to the strokewidth and length (i.e., $A = bT$, where b is the length of the stroke),

$$D = \beta v_B t_C, \tag{7}$$

$$t_C = \frac{\gamma_1}{v_H^{0.46} T^{0.27}}, \tag{8}$$

$$\sigma = \frac{\gamma_2 v_H^{1.46}}{T^{0.73}}, \tag{9}$$

and

$$S = T(1 + \alpha) + \frac{\beta\gamma v_B}{T^{0.5}}, \tag{10}$$

where

γ_1, γ_2 = function of paper and impactor mass:

$$\gamma_1 = k_1 \left[\frac{1 + q}{2kb}\, mw^q\right]^{\frac{1}{1+q}},$$

$$\gamma_2 = k_2 \left[\frac{m(1 + q)}{2kwb}\right]^{\frac{q}{1+q}},$$

v_H = hammer impact velocity,

σ = allowable ribbons stress, and

γ = $\gamma_1(\gamma_2/\sigma)^{0.32}$.

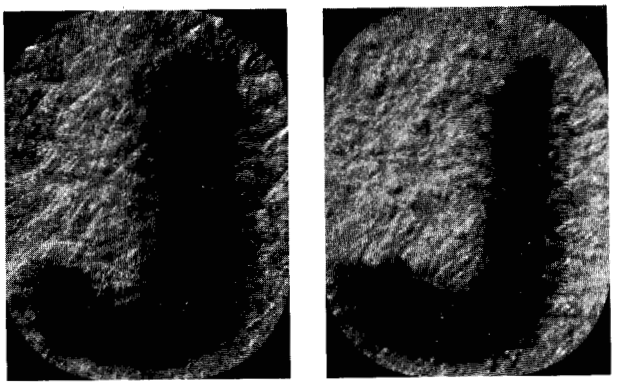
Now, for high-speed printers, it is desirable to minimize the dynamic strokewidth or slur without causing ribbon damage or excessive printed strokewidth. The above relationship shows that by increasing T, the character strokewidth, we obtain a printed character that has very good edge sharpness. The total printed character strokewidth does not become excessive because for the gain in static strokewidth there is a corresponding loss in dynamic strokewidth.

There are constraints to the upper limit of T. For aesthetic purposes, the width of the printed vertical strokewidths should be similar in magnitude to the printed horizontal strokewidths. As the value of T increases, the character area increases proportionately. As the character area increases, the impact force or impact energy must also increase proportionately in order to maintain high print density. Since the source of energy for the print hammer is electromagnetic, there is an energy limitation. This energy limitation is based on heat generation and dissipation and also on power.

Another limitation on the strokewidth T is the overall size and shape of the character. For relatively small characters that contain small enclosed white spaces like the characters %, @, a, etc., there is a problem of character fill. In other words, the wider strokewidths tend to fill the entire self-contained white space, producing a solid dark area and thus giving very poor definition to these specific characters. This problem is amplified on a six-part form, since the strokewidths are longer due to the longer contact times on six-part forms.

Conclusions

A new font design with larger character area has given, in general, excellent print quality results. However, font redesign of some individual characters may be required because of such factors as character fill, character height, and character aspect ratio.



(a) (b)

Figure 6

Comparison of printed characters: (a) narrow font at lower energy; (b) wider font at higher energy. The predicted difference in printed static strokewidth is evident.

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